Marcus Bianchi: Just give it some time for people to join.

[Break in conversation from 0:00:19 to 0:01:09]

Okay, just give it some time for people to be able to join.

[Break in conversation from 0:01:13 to 0:01:56]

Okay. Two minutes is usually enough for having everybody able to join. Welcome. This is the Better Buildings Space Conditioning Technology Research Team webinar. Today we will talk about efficient hot water systems, and we have an interesting set of speakers and topics on this webinar today.

I'm Marcus Bianchi. I work at NREL and lead the Space Conditioning Technology Research Team, and I also am manager for the Commercial Buildings Controls and Analytics Group at NREL.

We'll have an agenda for today. We'll have some questions to address some of the polls so we understand better who is attending. I will provide some updates from both the Better Buildings Alliance's Space Conditioning Team and then some updates from the DOE. And then we have our speakers, Lyle Keck and Adam Williams, and then we'll follow their talks with some Q&A to address whatever questions you may have. So as you have questions, please submit them in the Q&A so we can actually go through them and select some of them to be answered.

To provide some updates from the Space Conditioning Technology Research Team, we are myself, Dr. Michael Deru, Kelsea Dombrovski, and Dr. Chuck Booten. We all together work on the space conditioning team at NREL. Please, if you're interested in receiving information about what we do and the new resources that we come up with, please send a message to the email that is on the screen to get updates and be part of the mailing list.

As a first update, we provided some guides, both in English and Spanish, for multiple topics. In this case, we had HFC phase down, refrigerant phase down, heat pump water heaters and healthy buildings. They are all linked there. We have a series of webinars, which this one is part of it, and all of those webinars are being recorded, and they actually go into a repository that you can actually look at again. And we maintain the HVAC resource map, which is a repository of information around HVAC for commercial buildings.

For DOE, we have a new resource that was developed, which was the Large Commercial Building Boiler Electrification Guide. And then DOE has a new accelerator on commercial building heat pump accelerator. It was launched last month, and the link is actually there. We need partners to actually participate, so please follow the link and consider becoming a partner. And then there's the ongoing campaign on smarter small buildings which is also linked on this page.

We'll go through some polls. So join us at Slido. The link is on the chat. Hopefully everybody can see it and follow that to actually be able to answer the questions. I'm going to do that too just to make sure that it can be done. So what sector best describes your organization? Could you please respond to that? Still people responding, I guess. Thank you. Great. I think we have pretty good answers, I guess. Next one, please.

Yeah, why are you here today? What's your interest in this topic of hot water systems? Excellent. What type of resources are most helpful when you need to learn more about any topic on space conditioning? Thank you. Thank you for answering. This is very helpful for us to define where we're going to go. What space-related challenges would be helpful to have more resources on? So which topics are challenging to get responses to? Excellent. So many topics. Just waiting for the participants that are still typing. Those are very helpful for us to kind of identify areas that we can actually create resources on. We will continue to capture that. I would suggest to keep that one open. I suspect that this is the last one.

We obviously invite speakers of the time. One important aspect is that we don't endorse any particular commercial solution for anything. The reason for having those webinars is to have information being shared, so we invited two speakers. So the first one is Lyle Keck. He is Building Performance Practice Leader for Affiliated Engineers in Seattle and Portland offices, guiding the sustainable design services and champion high-performance design on projects around the region. His group specializes in energy, carbon, water, and resilience design across all of AEI's main markets, including energy and utilities, healthcare science and technology, and higher education. He is actively working in district energy and campus decarbonization markets with both planning and implementation projects that support a clean energy transition away from fossil fuel. He also participates with industry working groups such as the MPP 2040 challenge and the International Institute for Sustainable Laboratories. Lyle, please.

Lyle Keck: Thank you. Thanks to Better Buildings and NREL for inviting me today, and thanks to Marcus, Kelsea, and Kiara for coordinating and moderating this event. My name is Lyle Keck. I work for Affiliated Engineers here in Seattle, Washington. I lead our Building Performance Practice in the Northwest, focusing on energy, carbon, water, and resilience, and I've been involved in numerous decarbonization planning and implementation projects, both at the building and district utilities scale. So I'm here today to share some high-level challenges and solutions that are common to boiler retrofit projects and share some of those experiences from the field. Adam, who will be speaking next, is going to take a deeper dive into some of the specific applications with his case study.

So we're here today to talk about boiler replacement projects, electrification strategies for fossil fuel boilers in existing commercial buildings with the goal of minimizing onsite fossil fuel use, transitioning over time to clean, renewable, and low-carbon energy sources, and in many cases, improving energy efficiency and reducing operational costs. We're really talking about taking high-temperature heating hot water system, let's say 180 degrees or greater, or a steam to hot water, or even a direct steam system and retrofitting that to be able to use lower temperature heat-pump-based technologies. And so the general topics for today are organized into these three buckets on the left-hand side. You'll see we'll be talking about building conversions, primary equipment, as well as lessons learned for project execution and operations. The photo here is a natural gas fired hot water boiler from the field.

So the objective and kind of talking first about building conversions is the need that you need to ensure that the zone level and the building level HVAC heating devices are compatible with the new low-temperature heating hot water systems. In some cases, a VRF or a package solution might fit the application, but today we're really going to talk about the very common challenge in large commercial buildings of transitioning to a lower-temperature heating hot water system for electrification and decarbonization purposes. And some of the objectives are shown here. A main one of going to lower-temperature systems is compatibility with modern heat pump technology and the ability to accept lower-grade heat, whether it's a heat source or a heat sync from a variety of sources in the building or in the local environment. And so this compatibility and sort of wide range of operation is really important, especially at sort of smaller pieces of equipment or the smaller commercial building scale. It's also more energy- and carbon-efficient as compared to combustion, fossil fuel combustion, or electric resistance. And when we talk about lower-temperature heating hot water today, I'm really kind of talking about the range of 110 to 130 degrees for sort of standalone buildings. If we're talking on a larger scale, whether it's a campus district energy system or more of the industrial scale, we can get closer to 150- or 160-degree F is kind of the common temperature for those, and so when we're talking about converting to lower-temperature hot water, those are kind of the ranges we're talking about here.

So some of the challenges and solutions to the building conversion aspect first, and really any type of building conversion project comes with a high degree of risk and cost uncertainty. This is messy work, it's detail-oriented work, and you often don't really know the full conditions until you begin construction, so you should be planning for schedule and cost contingencies early on with this type of work. You're also working in an existing space. There's a lot of space constraints. You might be having cramped space, there might be structural limitations for placing heavier equipment or placing equipment at all higher up in the building or on the roof. You also may not be able to fully decommission any existing equipment until the new system is fully operational. So again, these are some common challenges. Maintaining operations and business continuity is important as well. There might be critical systems, critical functions, critical services that do not have the ability to shut down at all or for long periods of time to transition the heating hot water system. So you might need to maintain parallel efforts and plan for how you can overcome some of those and maintain business continuity, and again, just project-to-project, these are very kind of unique solutions. Very often it is sort of a copy-and-paste type of effort from project to project or building to building.

So some approaches to mitigating a few of those challenges include a very common practice of what's called hot water stress testing, and this is where you incrementally lower the heating hot water supply temperature during a cold snap or winter months and sort of see how low you can still maintain the current operations and space conditions. So you might start with 180 and take it down in 5- or 10-degree increments and kind of see what happens. You may find out that, for example, you only need to replace the air handling unit coils instead of every terminal coil in the building, so the outcome of this stress testing is to affirm design conditions as well as really focus in the scope of the building conversion project so that it's feasible and it's cost-effective and practical.

A few other approaches are kind of dealing with process needs separately. Many existing buildings with high-grade heat sources serve all of the needs in the building off of that source, so looking to de-camp some of those process or specialty needs off of your main system and really not make sure that you're overdesigning. Try to avoid sort of having the tail wag the dog type of scenario, and so deal with process needs separately. And additionally, kind of maintaining a fossil fuel backbone during the transition is something that's very common practice as well.

Moving over to kind of primary equipment and getting into selection and right-sizing, here are a few of the objectives: minimizing not only first costs but lifecycle costs; maximizing annual energy efficiency and reducing, if not eliminating, operational carbon emissions Day 1 or over time; and lastly here, resilient systems and the ability to reliably deliver heat throughout the year and under peak conditions is really, really important for most clients. At lower outdoor air ambient conditions, air source heat pumps derate significantly, they have defrost cycles, there's a lot of cycling, so having sort of multiple sources of heat or having some type of higher temperature solution for peak conditions or critical operations is another main objective of this type of boiler replacement project. And you can see the photo in the bottom left-hand corner here is an air source heat pump being installed in a zero-energy-capable laboratory facility here in Washington.

So some approaches to this is really trying to right-size the heat-pump-based or heat-recovery-based heating technologies to deliver a majority of the annual heating demand and not necessarily deliver all or 100 percent, but try to get the biggest area under the curve, if you will. Using supplemental peaking or trim devices such as fossil fuel or electric boilers is a really good way to make it first-cost efficient and kind of develop a practical and efficient solution. And oftentimes you'll see diminishing returns or sort of exponential needs to get from, let's say, a 90 percent carbon savings all the way to 100 percent carbon or full electrification. So kind of right applying a supplemental device for peak or trim heating is very important. And usually it has a very minor impact on the annual energy and carbon efficiency, or the operational costs if you're only really using it under this mode of operation. And some rules of thumb that we use as sort of for a quarter to a third of the peak heating capacity, that will generally supply less than 10 percent of the annual heat to your system. So again, finding that sweet spot, finding practical first-cost-efficient solutions, and then having a sort of minor overall annual energy penalty or operational cost penalty.

Thermal energy storage is another key approach. Domestic heat pump water heating, sort of best practice nowadays is to include some sort of storage and minimize the size of the heat pumps and run those heat pumps more continuously. And thermal energy storage in general separates the demand side from the production side, which really opens up a lot of opportunities relative to peaking capacity and improving the reliability of operations. And lastly, I would be remiss to not mention consideration for electrical impacts. As we're putting a lot of the heating system now away from fossil fuels onto electric, existing electric service size, even some limitations that the – sort of beyond the building from the substation level or beyond become very real when you start considering these things. So balancing the electric resistance that you're using with heat pump or fossil fuels to minimize that electrical impact, and often what you'll see is that the peak electrical demand gets shift from the summer cooling months more toward the winter heating months with the building that is fully electrified.

One other kind of hot topic today is refrigerant selection when it comes to the types of heat pumps or electric heating and cooling equipment that's out there. It's top of mind. There's many state and federal phase downs and phase outs that are in effect now. ILFI or other LEED certifications are taking more mindfulness of refrigerants and their global warming potential, and really just a growing awareness of the embodied carbon and MEP systems through things like the MEP 2040 challenge. You'll see here 134A and 410A, which are circled in red, are some of the more commonly used refrigerants with higher GWPs. Generally we're targeting below sort of a 750 GWP or a 600 GWP for a lot of the phase downs and phase outs. But what you'll see is that 513A or R32A, sort of just below that 750 threshold, these are kind of common drop-in refrigerants today, but it's not likely that we'll see those in five or ten years as much, and we wouldn't really call them ultralow GWP refrigerants.

On the left-hand side here, you can say that there's a lot of different types of considerations and tradeoffs for selecting these. You have capacity considerations, there are space requirements, you might have different flammability classifications which impact the cost or the types of systems surrounding the space that the equipment is in. And so if you were to go, let's say, to an ultralow R1234ZE, which has a GWP of 7, it does come with a larger footprint and a lower capacity relative to 134A or what's on there today. So even if your facility was planned for expansion, you may have different needs just given the new equipment that's available for today.

So I wanted to illustrate, and here's a sample of projects in different climate zones, kind of largely across the west and Midwest in this case. You can see that sort of the base technology for this is heat recovery chillers throughout, or some type of water-to-water heat pump that produces heating and cooling simultaneously. Below that in blue, you'll start to see a mix of kind of right-applied technologies. These are super-efficient technologies, but they might come with some cost constraints or some technical limitations, and so these are kind of your workhorses that are right applied in the middle. You see a mix of geothermal heating and cooling, some thermal energy storage, and maybe even using the building exhaust air as a source of heat pump heating and cooling.

And then below that, at the very bottom and left, you'll see some of those peaking or trim devices. In more mild climates like western Washington or San Francisco, we see air source heat pumps. In more extremes or in Midwest cooling and heating climates, for heating you might see a gas boiler, a campus steam, and again maybe even a right-applied electric resistance or electro boiler for peaking. But again, really this is just to sort of illustrate that across a wide variety of climates and project types, electrification and boiler replacement is achievable, but it usually involves a mix of strategies and a mix of different strategies kind of right applied to your building and right applied to your climate.

So following up today with some higher-level lessons learned on project execution and operations, I say that again but I'm going to say it – or I said it before, I'm going to say it again here, but really just plan for contingencies in the building conversion work. Plan for schedule and cost contingencies and unforeseen conditions that might come up during construction and really working with partners, both your builder and your designer and your owner-partners who are engaged throughout and who can make quick corrections together when things arise as important strategy for this.

Another lesson learned is that there are really large energy and carbon savings from this type of work, but sort of temper your expectations on the operational costs. By comparison, there's a much smaller reduction in operational costs, if not a wash, but usually there'll be a smaller reduction in operational costs as compared to the magnitude of energy and carbon savings overall. But when you look at lifecycle cost analysis and sort of right applying equipment from a first cost standpoint and sort of only using peaking equipment minimally throughout the year, it's still very lifecycle cost effective.

Lastly, reducing complexity of controls. You know, when you start to look at large heat pumps, they have turndown issues. They want to operate continuously at higher loads, and now you're taking separate cooling and heating systems and often combining them into a combined heating, cooling, and heat recovery system, which is just inherently more complex to operate. And so trying to minimize complexity during design, even if it makes some tradeoffs to the optimal efficiency or the optimal strategy, simplifying complexity in selection and design helps a lot, as well as just a thorough commissioning, measurement, and verification throughout all seasons and throughout sort of the maturity of the building as it gets fully utilized and fully populated.

And lastly, a phased approach, being able to break down a bigger task into multiple incremental steps, having a strategy, and being able to execute some of those in a phased or incremental approach really leads to success. You might not have funding at the beginning to do it all, or there might be other sequential challenges to the type of work or the type of operations that might lend themselves to a phased approach. As long as you're setting the cornerstones first and making sure that you're building toward the optimal solution and leaving the door open for those future integrations or for getting from 80 percent to 100 percent savings in the end, these are all sort of key opportunities within the phased approach and sort of an incremental execution of the scope as funding and other needs allow. That wraps up my presentation here on some of the higher-level challenges and solutions, and I'll toss it back over to Marcus to introduce our next speaker, Adam.

Marcus Bianchi: Thank you. Thank you so much, Lyle. Before I go into the next speaker, submit your questions in Slido on the link that was provided. We're collecting the questions so in the end we will actually manage answering some of those questions in a panel discussion. I'll try to moderate those questions and ask each one of the speakers for their input. Thank you for doing that.

Now the speaker is Adam Williams. He has spent eight years providing HVAC design, analysis, and commissioning services for commercial buildings, including high rise buildings, laboratories, data centers, and medical office buildings, primarily in California. Adam is a senior mechanical engineer at Taylor Engineers and HVAC and plumbing consulting from Alameda, California. Along with providing high-performing and practical designs, members of Taylor Engineers are key contributors in ASHRA, including key leadership in the standards 90.1, 62.1, 55, as well as key contributors to the HVAC sections of the California Title 24 energy code. Adam particularly enjoys the challenge associated with retrofit projects and is pleased to share his HVA retrofit at the East Palo Alto Government Center. Adam, please. Thank you.

Adam Williams: Hi, Marcus. Thank you. I want to talk about the East Palo Alto Government Center. So this is an existing three-story, 50,000-square-foot building. It's got a library on the ground level and then the rest of it is primarily office space. This is in East Palo Alto in the San Francisco Bay area. The building is about 50 years old. There was a substantial mechanical retrofit about 30 years ago, and then we were hired right before the pandemic to work on the design, and construction will be done in about a month or so. So that's about the timeline.

So the existing system is a water-cooled chilled water plant that serves one built-up multiple-zone VAV air handling unit, which then serves many VAV reheat terminal units. So those terminal units, they have a damper that can modulate the amount of cooled air to meet the cooling loads, and then they've got hot water piping to a hot water reheat coil with a hot water valve that can be modulated to heat up the air to meet the heating loads, and that's served by a natural gas _____. That's the existing system. The original project scope on this was to basically do a full gut retrofit, provide modern equipment with modern controls, primarily to resolve a lot of temperature – a lot of comfort issues they were having due to the old equipment, and then also solve some zoning issues, rezone some of the terminal units around to solve some additional comfort problems. So that was the original scope.

And then as we started in schematic design, the owner came back to us and said, hey, could you guys investigate an all-electric retrofit. Many municipalities in California are highly encouraging and sometimes even mandating fossil fuel phase out for new construction, and they wanted to set an example on their retrofit project and said if we're going to tell stakeholders to go all electric, we should go all electric too. And also, their building has a lot of existing onsite solar already, so they wanted to utilize that with an all-electric system more effectively.

So we started looking at some concepts. I'm going to go over this. Initially we looked at electric resistance heat very quickly because – so the idea is if we're going to replace _____ units, we could just put in electric resistance heating coils. And it's simple, fairly low cost, but it's not very efficient. For every unit of electric power you put into those, you get one unit of heat out, which isn't very efficient. And the existing electrical capacity at the building could not provide a full electric resistance heat for the whole building, so it wasn't going to work electrically, and it's not really allowed in Title 24 of California energy codes for this approach. So we didn't seriously consider this, but I'm pulling it up because that would be the challenge with electric resistance heat would be electrical capacity and efficiency concerns.

The next idea we looked at was a variable refrigerant flow concept. For those who aren't aware of this system, you have a heat pump condensing unit connected with refrigerant pipe to many fan coil units in the space, and then there's a dedicated outside air system that provides ventilation. And on this building, we had a house air system that's sized for the whole cooling load, so we would have an oversized DOAS system, which could provide 100 percent outside air free cooling, which does save a lot of energy in a mild California climate to have a full _____. So this system would be efficient. A heat pump system is going to have a COP of three to four, so for every unit of electrical power you get, you get three to four times the heating output, so it's three to four times more efficient than electric resistance heat.

The problem with this is the building was not set up – was not designed with fan coils in mind, so it was an old hot water piping distribution would have to get taken out, replaced with a brand-new refrigerant piping distribution, and retrofitting all the floors in the building for this VRF solution proved to be very expensive. So other concerns with VRF if you have a whole building's worth of refrigerant charge, and if that leaks into a space, that can be a health and safety concern. Now, refrigerants aren't generally toxic, but enough volume of that could dump in a space to displace enough oxygen that there could be a health and safety issue. Also, at the time of designing this, it would be designed with _____ 10A, and that would be – it's a high greenhouse gas emitter, and refrigerant leakage is more likely with field-installed piping, so it is a fair concern. The other concern that owners and operators sometimes have with VRF is that the manufacturer's providing the condensing unit, the fan coil unit, all the controls associated with that, and you're kind of married to that manufacturer once you design it, and you're dependent on that manufacturer many times for service, for TI retrofits, future modifications and changes to the system, so some owners aren't okay with it. So this was looked at, but we didn't end up going with it, so let's go to the next slide and we'll look at the solution we did go with, which was air to water heat pumps.

So these units pump heat from the outside air to your hot water piping, and they can run as an air-cooled chiller the opposite way, basically, where they pump heat from the chilled water to the _____. And so these units can generally do both, and in California, these were – the size of the units you would need to meet your heating loads generally is pretty close to the size you need to meet the cooling loads for general office applications. So we're going to replace our water-cooled plant and serve heating and cooling. So these are heat pump systems, they are efficient, a lot more efficient than electric resistance heat, and it was more affordable than VRF because less work needed to happen down on the floor levels. The challenges with this, which I'm going to get into in the next slides, are low hot water temperatures as Kyle mentioned, size and weight concerns, and there's some additional design considerations, controls complexity, other challenges associated with this design.

So the first thing, low hot water supply temperature. As Kyle mentioned, boilers are generally – can be about 180 degrees hot water supply temperature, and many systems are designed for that high of hot water supply temperature going through the pipes and the coils, so the piping and the coils are sized to accommodate that. The heat pumps generally can do about 130. There are some modern heat pumps that can do 140, but beyond that, that's generally what most of the current technology is doing is about 130-degree hot water supply temperature. And when you lower that hot water supply temperature, you need to make sure that there is enough coil capacity in the building to be able to deliver the BTUs that you need space at that lower temperature. So the question is how do we retrofit this building without having to replace everything, all the piping, all the coils?

So the first thing we did, like with any all-electric retrofit, is we do load calculations. We don't just match the existing equipment size because our experience is then that many times heating systems are oversized, and that's in part, I think, because existing load calculation technology has gotten more sophisticated, we're less conservative with calculations and more aggressive in trying to right size this. Also, traditionally, the cost differential between a 1-million BTU boiler and a 1.5-million BTU boiler is not that much, relatively speaking. So I don't think as much risk was taken in trying to right size heating systems, whereas now it very much matters, the cost associated with these equipment. So we really try hard to right size and do load calculations to get the right size heating system. And half of it is doing that and half of it is convincing an owner, especially on an existing building where they might have comfort problems, that your heating system is oversized. We want to provide a smaller sized heating system. That can be a hard conversation to have, but it is worth having to try to make this work affordably.

The next thing we did was we were already planning on replacing the reheat terminal unit, so we said, well, let's upsize those terminal units because we're already replacing them. Let's make them have as much capacity as possible. So the way we did that, we increased the rows, the depth of the heating coils. So you can generally get heating coils as one-row, two-row, or three-row heating coils typically. So that's how deep – let me mark up this. We're talking the depth of the coil here. And when you're at a building, you can generally see these two _____, so this is a photo of a two-row coil, which is what we ended up going with in most cases. So if you go – so the more rows deep, the more heating capacity you get, but also there's more increased air side pressure drop, and we're trying to reuse the existing supply fan. So we didn't want to increase it to three rows. We did two rows deep coil. That's a good compromise.

And then the other thing you can get is you can get oversized coils. So let's say you need a 10-inch VAV box, you can ask the manufacturer to give you an oversized VAV box, and they'll give you a 12-inch VAV box with a 10-inch inlet. So you get a bigger coil, and that gives you more capacity and a lower air side pressure drop because the air is going slower through that coil because you've got a bigger coil. So that's what we went with was two-row oversized coils to increase the heating coil capacity at the lower temperature. Next thing we did, we upsized our hot water pump. Again, what we found is that you can increase the flows through hot water systems by a little bit before you run into noise and erosion problems associated with increasing flows through existing hot water pipe. So we did all of that, and that significantly minimized the amount of new piping distribution that we had to change, or add basically, to make sure we didn't run into problems. So that was the priority was do load calculations, upsize equipment that we were already planning to replace, and to minimize any new equipment that had to be – new piping basically that had to be added as a result of this project.

So other things that can be done but weren't necessarily done on this job, if you have a system with good controls and trending capability, you can check – you can use trend analysis to validate your load calculations. This building, the controls were not – didn't have that functionality and weren't necessarily trusted by all the stakeholders, so we didn't really go that way. Other thing you can do is, kind of like Kyle mentioned, you can do testing too. You can say, hey, on this early morning, try lowering your hot water temperature. The problem with that is that (A) if you're planning on replacing the coil anyway, you do that test and people say it was uncomfortable. And you're like, well, we're going to replace out equipment, so you should trust us. That can sometimes not work out very well if you're already planning on changing the system. Other considerations with that too are that the boilers – generally, noncondensing boilers don't like running at that low temperature. You can prematurely wear out your boiler, and so operators are sometimes concerned about that, like hey, are you going to wear out our equipment by running this test. So those are considerations.

Also, sometimes your design schedule doesn’t really accommodate running a test early in a winter morning. Other things you can do, there are heat pumps that work with higher hot water supply temperature. There are heat pumps that have CO2 refrigerant that can work at those hot – provide higher hot water supply temperature. Our experience is that those are really expensive and that generally it makes sense to do – those become cost prohibitive and it makes more sense to do the work down in the space than use those heat pumps that provide higher hot water supply temperature. Also, those units are a lot less efficient, but that is an option.

The other thing that we have seen and have experience and learned some lessons on is some people say why don't you just add a booster boiler to – if you're concerned about providing 130 hot water, why don't you add an electric or gas booster boiler in series with the heat pump and heat it up to 150 degrees, and send that to your coils. But the problem is, if you're not getting the right delta T across your coils, the hot water return temperature can come back so high that your heat pumps can't really do anything with it. Either the heat pumps curtail their heating capacity and say, oh, you sent us 127-degree water. We'll heat it up to 130-degree hot water and just run one of our compressors. Or they'll just trip because the return water temperature is too high. Now your heat pump doesn't really do what it was designed to do, and you're running only on the booster boiler. So this is just something to keep in mind. I should clarify what Kyle said about adding gas boiler or an electric boiler to supplement. That's a fine approach, and it's very practical in many cases, but you just need to be aware that it's hard sometimes to run your heat pump and a booster machine at the same time, simultaneously, and it may make more sense, if you're going to plan on a booster boiler on the peak, the coldest days of the year, size that to run without the heat pump doing anything because it may not be able to do anything if you need those high hot water temperatures to work.

Next big issue is size and weight challenges. So here's an example. The box on the left is a 3-million BTU boiler, and then the units on the right are 3-million BTU of heat pumps at 29-degree outside air temp. Significantly larger. These need to be outside, and they take up a lot of space and are heavy. So this is definitely a concern and something we look at on all our buildings. Where are they going to go? They can't go where the boiler originally went. Fortunately, this building had a lot of rooftop space, and they weren't eager to fill it up with solar panels. They had a bunch of solar panels already, not on the roof. And so the space wasn't a big issue, and yeah.

So as Kyle mentioned, defrost is something you need to be concerned about. You're pumping heat from the air to the water, and as it gets colder, these units have to run in a deep frost cycle. Basically, they run in reverse, and instead of being a heat pump, now they're a chiller to warm up the outside air coils so they don't freeze. The photo on the right is what happens when the defrost cycle doesn't work and you freeze up your coils and the unit doesn't work. So these run in a defrost cycle, and when they run in a defrost cycle, they're not heating, so that limits the amount of capacity that they can output. So the key thing is – so you need to tell your manufacturer to give you the D-rated heat pump capacity that accounts for the defrost cycle. Because at least when we were designing this, not all of them were doing that. we had to specifically ask for that D-rated capacity and account for that. So other option is you can go with an electric resistance defrost mode, but you just need to make sure that that's accounted for by your electrical engineer and the building electrical demands can handle adding an electric resistance station for defrost.

The other thing with these heat pumps is that they generally require a lot of water volume in the system for stable operation to avoid turndown issues and other things associated with – for example, when these run in a defrost cycle, they're going to spend a few minutes each hour running the wrong way, running as a chiller rather than a heat pump, and they want to have a sufficiently-sized buffer tank so that they can provide stable temperature control, even during those defrost cycles. So buffer tanks and system volume requirements are not – are common for all chillers, but these heat pumps can sometimes require a lot of system volume. And also, some of these heat pumps like primary secondary piping, which means that you don't get to utilize as much of the building type as you would like for the system volume. So what this ended up meaning on our job is we required a large buffer tank. These are basically big tanks to increase the system water volume in the pipe, and these are really heavy. We needed a 4,500-pound hot water buffer tank and a 7,000-pound chilled water buffer tank, and these are like five-foot diameter tanks. They're really heavy at a point load, so these can be a big structural challenge as to where to put these. Fortunately, on our job, we had an existing water-cooled chiller, and we were able to put these where the water-cooled chiller used to be, which allowed us to reduce all the structural requirements for these, so that worked pretty well.

So the final thing to think about with heat pumps is you can get units as a two-pipe unit or a four-pipe unit. So the two-pipe units, they can do heating or cooling, but they can't do both simultaneously. So they have changeover valving so that they can provide heating or cooling, but not both. These are generally more economical and cheaper, and they have generally more simple controls. At least the factory controls are more simple because they're doing one or both. The other option is a four-pipe heat recovery heat pump, or heat recovery chiller sometimes called. These allow you to do simultaneous heating and cooling, and they can have the evaporator be the chilled water side and the condenser be the hot water side, so you can recover heat from your hot water to your chilled water, which his more efficient when you have to do simultaneous heating and cooling. The problem with these is they're more expensive and they have more complicated factory controls because the factory controls generally decide whether you're running in heat recovery mode, whether you're rejecting to the outdoors, and the staging for heating and cooling, so it can get more complicated.

So on our job, we did some energy modeling to look at both the peak heating, the peak cooling, and also the simultaneous loads at a mild 70-degree outdoor air temperature, and we found that although the simultaneous loads don't happen that often, they're generally pretty high. They're high enough to have us consider doing one heat recovery machine to handle those simultaneous loads and provide efficient operation during that, and one two-pipe unit for affordability. So that's pretty much the job, and I'll wrap it up.

Marcus Bianchi: Thank you so much, both of you. I'm going through Slido and some of the questions that got submitted. Let's use the time that we have to actually address some of those. There are a couple questions about the commissioning and the stress test that I would like to hear from you, which is what are the common issues that you have seen during the stress tests or the commissioning of those systems, and are there recommendations that could make future projects more successful?

Adam Williams: I think my experience – well, with commissioning, I think the first thing is understanding the factory controls from those heat pumps can be something that's very challenging, and it's important to, early on, make sure that you really understand those controls and how the staging of the units because many of these heat pumps are modular. They're a lot of little modules, and how they stay up and how they determine when to go in heat recovery mode and not can sometimes – is complicated and sometimes you have to really ask to really get the literature on how those controls work. So that's been my experience on the commissioning side for these heat pumps.

Marcus Bianchi: Lyle, would you like to add something?

Lyle Keck: Yeah, I mean, probably just some more general commissioning tips, but early engagement is very key. Getting the commissioning group engaged early during the design goes a long way. Making sure metering is set up properly so that you have the correct points recorded, they're in the correct units or conversions, so metering is very big. And then a lot of – more specifically, we see a lot of sort of low load initially or low delta T beyond what was designed, and that can really trip up heat pumps or simultaneous operation quite a bit, so looking at low load or low delta T and trying to mitigate that. There's a variety of approaches for that, but that's a very common early hiccup with trying to start up heat-pump-based heating and cooling systems.

Marcus Bianchi: Thank you. I'll follow up with you immediately. You mentioned some rules of thumb to size the system. What are some alternatives to upsize the system properly?

Lyle Keck: I think Adam mentioned using energy modeling and trying to develop an annual heating – hourly heating and cooling profile. This is a big one to really kind of right size and figure out sort of the inflection points or the sweet spot, if you will, between first cost, lifecycle cost, and sort of operational performance. So that could be a simple box energy model. It could even be just some 8760 load profile analysis. It doesn't have to be a super detailed whole-building energy model if that's not available. But looking at some type of hourly information is one, and then just kind of trying to find that sweet spot or that inflection point, looking at kind of first cost and operational cost sort of side-by-side.

Marcus Bianchi: Great. I'm going through Slido and the ones that actually got some thumbs up, so one that came to the top is what are the major drivers for risk? Asbestos is cited as one example, but how much contingency should you set aside as a percentage, and if it scales with just age or are there other risk mitigations that you could actually do there?

Lyle Keck: I can take a first crack at that. I think you should approach risk like you do on any other project, and then higher level early when it's really just concept design or early planning, you assign a higher level of risk and contingency to that, and then hopefully when you get more into the implementation or real design phases, you can reduce some of that. Ten to fifteen percent on sort of the building conversion scope of work is kind of a good range, but I'd try to separate it out between that work and let's just say the primary equipment or sort of the central plant type of work if you can assign different factors to that. And as far as linearly with age, age is certainly – and building vintage, system type is a good starting proxy, but thinking about sort of the number of components, the number of systems, do you have just one steam riser in your building or are there seven steam risers going to 15 different hot water converters? What's the space? Are there pinch points? Are you trying to get in and out of a subgrade, cramped mechanical room versus working on a roof? And a big one too is maintaining operations and the risk associated with that, so what's the building type, how much do you need that heat to be there? If it's something that you can shut down for two or three weeks or even throughout the cooling season, then it becomes less risky. So if you need to maintain those operations completely, that's a big risk in cost factor. Adam, do you have other thoughts?

Adam Williams: Yeah, I'll add to what Kyle said. I think almost all these all-electric retrofits are going to involve not just work on the roof. It's work in the space too because even if it is a VED reheat system, it's a VED reheat system for 180-degree water, not 130-degree water. And work in space is generally concealed under a ceiling, and many design consultants are working based on as-built drawings which many times are not actually the as-built configuration, as I found out on this project, answering many RFIs and things where the as-built drawings showed one thing, but in reality it's different. So I think the answer is I think ways to mitigate that risk are early on in design, if you're an owner, ask your consultants, hey, have you found discrepancies between your as-built drawings and the actual as-built condition, and help really clearly in design figure out, oh shoot, my as-builts aren't actually as built. Maybe I need to get this resurveyed or reverify everything to try to mitigate risk in the space and areas that are concealed.

Marcus Bianchi: Thank you. A couple questions about thermal energy storage, so maybe would be interesting to address them, and they're really dealing with the use of thermal energy storage for that. I think we can only do this last question because of the time, but there was some mentioning about using thermal energy storage. What are your thoughts and the size of the capacity that is necessary to maintain that?

Adam Williams: I can take a stab at that. So at least in California, we have the luxury of, even on the coldest days, it still kind of warms up in the afternoon, and the heat pump capacity very much depends, at least for air source heat pumps, on the outdoor air conditions. So if you design enough thermal energy storage that you can handle all morning, now you can design your system to provide the heating load in the afternoon. So we're actually, on very large commercial buildings, we are using thermal energy storage to significantly reduce the amount of heat pumps that we need because there's no real option. On a high rise, there's not enough roof space for all – for a bunch of air source heat pumps designed for the peak load on the peak morning. So we'll add thermal energy storage so that we can downsize the amount of heat pumps we need to meet the peak load later in the morning and afternoon because we have thermal energy storage to smooth out that peak. So I think the question of how much to size it is a really complicated question, not something I can answer in one minute, and it very much depends. Very complicated question, but that's kind of the idea.

Marcus Bianchi: We are at time. We'll collect all the questions. We're going to go and _____, but if you want to join the mailing list, please send a message to us. Adam and Lyle, thank you so much for both of you presenting, and thank you so much for attending. See you.

[End of Audio]